Correcting agglomeration economies: How air pollution matters

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Correcting agglomeration economies: How air pollution matters

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Abstract

The aim of the paper is to correct standard measures of agglomeration economies in order to account for air pollution generated by commuting. This paper examines the impact of nitrogen oxide (NO_X) on worker productivity. NO_X emissions are primarily released by the transportation sector. Literature on agglomeration economies is abundant and highlights the positive role of density on productivity. Nevertheless, this literature does not take into account the environmental impact generated by a better accessibility, namely commuting. We first develop a general framework to estimate the agglomeration economies for the 304 French employment areas. In line with the literature, we find an estimate of 0.05 for the elasticity coefficient of productivity with respect to density. Then, we introduce NO_X emissions. The estimates suggest that emissions reduce the positive effect of density on productivity by more 13%. The model confirms that air pollution matters. Agglomeration economies should be corrected by the environmental impacts associated with the enhancement of accessibility such as the implementation of a new transport infrastructure or policy.

Keywords: agglomeration economies, accessibility, atmospheric pollution, transport policies

JEL: O18, R23

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1 Introduction

Agglomeration economies play a key role in urban economics. The very existence of cities or of any concentration of activities can only be explained in the light of increasing returns in production activities, provided we rule out the role played by the attributes of physical geography (Fujita and Thisse, 2002). Agglomeration economies are positive externalities derived from the spatial concentration of economic activity (firms and households) that affects the productivity of firms. They constitute increasing external returns to scale with respect to the size or density of population or employment.

Studies generally estimate the net agglomeration effect and support evidence that agglomeration positively impacts labor productivity. Concentration of economic activity was first defined by the size of the population or employment, then with measures of density. Ciccone and Hall (1996) are the first to propose a framework investigating the effects of employment density on labor productivity. In more recent years, new geography economists such as Combes et al. (2008, 2011) enhance the basic framework by adding new elements such as market potential, land area, firms specialization and economic diversity.

Other authors (Graham, 2007; Rice et al., 2006) focus on the effects of a new transportation infrastructure on labor productivity. They conclude that a new infrastructure has a positive effect on accessibility, thus enlarging the opportunities offered to workers and leading to increased labor productivity. Nevertheless, none of the above mentioned studies take into account the environmental impact generated by an increased accessibility, namely commuting. Yet, enhanced accessibility increases air pollution, in particular NO_X emissions which primarily result from transportation. Epidemiologic studies show that atmospheric pollution has a negative and significant impact on human health (see e.g. Currie et al., 2009a, 2009b). The deterioration of health implies both lower labor supply (Ostro, 1983; Hanna and Oliva, 2011; Carson et al., 2011) and lower labor productivity (Lavy et al., 2012; Graff Zivin and Neidell, 2012).

This article aims at correcting estimations of agglomeration economies accounting for air pollution resulting from commuting. We add air pollution variables in the general framework studying agglomeration economies. More specificaly, we explore the impact of nitrogen oxide (NO_X) on productivity. NO_X emissions originate mainly from diesel vehicle exhaust. The objective of the present paper is to show that pollution has to be included in the estimations of agglomeration effects. Results confirm a negative and significant impact of air pollution on productivity.

We use aggregate data for the year 2009 for the 304 French metropolitan employment areas. The employment area level constitutes the relevant spatial unit for transportation projects and policies, as well as for studies related to the labor market (Combes and Lafourcade, 2012). Yet, very few studies are conducted on such a fine geographic level. In this article, we combine standard data of determinants of agglomeration economies, such as employment and wages, as well as data on emissions for one air pollution variable, NO_X. Data are disaggregated at the industry level into five sectors and then pooled.

First, we estimate the effects of employment density, accessibility measured as a market potential à la Harris (1954), surface area, economic diversity, and sectoral specialization on labor productivity per worker. In line with the literature, results show an increase in productivity of 0.05% for a 1% increase in employment density. Second, we introduce the variable measuring air pollution: nitrogen oxide (NO_X) emissions. In line with epidemiologic studies, we find that air pollution impacts negatively labor productivity. A 1% increase in the level of NO_X emissions leads to almost 0.1% decrease in productivity. Third, we compare the models with and without air pollution. When pollution is accounted for, the density coefficient is reduced. Then, we focus on an illustrative case to show the magnitude of the reduction in agglomeration economies when local air pollution is considered. When NO_X emissions are included in the model, the agglomeration gains are reduced by more than 13%.

Agglomeration economies are often enhanced by new transportation policies or infrastructures that improve accessibility and contribute to the densification of the area. However, improved accessibility induces trafic and therefore pollution emissions. So far as we know, the impact of air pollution on productivity is not addressed in specifications estimating agglomeration effects. In a sustainable development context, these results shed a new light for the assessment of transportation projects such as tramways or Bus with a High Level of Service. This study allows us to put into perspective the agglomeration benefits resulting from the implementation of a new transportation infrastructure or policy.

The paper is organized as follows. Section 2 provides a brief review of the literature on agglomeration economies. Section 3 presents data and descriptive statistics. Section 4 estimates the general econometric model and addresses common endogeneity issues. In section 5, we introduce the environmental variable and present the adjusted results. In section 6, we compare both specifications and develop the illustrative case. Section 7 concludes.

2 Literature review on agglomeration economies

2.1 Sources and classification of agglomeration economies

Already long ago, Alfred Marshall (1890) set the assumption that geographic concentration of activities generates productivity gains. Duranton and Puga (2004) explore the theoretical microeconomic foundations of agglomeration economies. They put in three distinct mechanisms leading to agglomeration economies: sharing, matching, and learning. First, learning effects or technological spillovers relate to the generation, the diffusion, and the accumulation of knowledge. The process of learning occurs at small spatial scales, since it requires close interactions and physical proximity. Therefore, dense areas make a higher degree of specialization possible (Ciccone and Hall, 1996). Second, large and dense labor markets allow for better employees/employers matching with lower search costs. Third, large and dense markets lower access costs to both customers and suppliers of intermediate goods and services, even when transportation costs are low (Krugman, 1991). Moreover, this last mechanism allows for the sharing of local public goods and of any other indivisible facilities, as well as the sharing of risks.

A further distinction can be made between "localization economies" and "urbanization economies" (Krugman, 1991; Rosenthal and Strange, 2004), though their sources are similar. Localization economies, also called within-industry externalities or Marshall-Arrow-Romer effects, imply increasing returns to scale that are external to the firm but internal to the industry (e.g. technological spillovers, intermediate inputs sharing, labor market matching). Urbanization economies, also called between-industry externalities or Jacobs externalities (after Jacobs, 1969), refer to agglomeration benefits that are external to the firm or the industry but internal to the city (e.g. local public goods sharing, input-output sharing). In this work, we do not aim at estimating these two kinds of effects separately. Indeed and as stated by Graham (2007), "an aggregate estimate of density externalities is sufficient to demonstrate the relationship between agglomeration, productivity, and transport investment".

The creation and growth of cities result from two opposing forces: agglomeration (centripetal forces) and dispersion (centrifugal forces) (Krugman, 1991; Fujita and Thisse, 2002). It is usually admitted that agglomeration effects follow a bell-shaped curve (Henderson, 1974; Fujita et al., 1999). Agglomeration economies first exceed diseconomies up to a certain threshold, and lead to concentration of activities. Thereafter concentration of activities leads to congestion and pollution issues, rising land rents, higher labor costs, crime and socio-economic polarization, which constitutes costs for society, and hence a dispersion force. In the literature, these two effects are rarely identified separately, and only the net effect is usually estimated, as in this study.

2.2 Magnitude of agglomeration effects

Several reviews of literature are available on this topic (see for e.g. Rosenthal and Strange, 2004; Puga, 2010; Melo et al., 2009). Although they are drawn on different methodologies and on countries (mainly the US and Europe) of various size and industry-structure, all the studies support evidence that agglomeration economies positively impact labor productivity. Depending on the measure applied, elasticity coefficients for productivity usually range from 0.03 to 0.08 (Rosenthal and Strange, 2004). This means that a 1% increase in either density or city size results in a 0.03 to 0.08% increase in labor productivity. Ciccone and Hall (1996) find that doubling employment density raise the average labor productivity by 6%, while more than half of the variance in output per worker across US states can be explained by differences in employment density. Ciccone (2002) finds similar results (4.5-5%) for five European countries. Combes et al. (2008, 2011) using the same measure estimates respectively an elasticity of productivity of about 0.08 on French departments, and of 0.06 on French employment areas with aggregate data, along with an estimate of 0.03-0.04 on French employment areas with individual data. Rice et al. (2006) stress on the fact that studies based on individual data show smaller coefficient values.

2.3 The impact of transport

Other authors focus on the effects of a new transportation infrastructure on labor productivity. Assumption is made that new or improved transportation infrastructures enhance accessibility, which in turn enlarges the concentration of activities from which agglomeration economies arise (Gibbons and Overman, 2009). Venables (2007) explores the theoretical foundations behind the effects of transportation infrastructures on productivity. He concludes that better accessibility leads to increased productivity. In an empirical study, Rice et al. (2006) and then Matas et al. (2013) confirm this finding and evidence a 1.2% increase in productivity when travel times are reduced by 10%. However, there is evidence from a steep decrease of agglomeration economies with distance (Rice and al., 2006; Graham et al., 2009; Matas et al., 2013). Therefore, a new transportation infrastructure mainly benefits to the surrounding area.

Agglomeration economies are additional benefits that are more and more accounted for in transportation project appraisals as "wider economic benefits" (Vickerman, 2007; DfT, 2005; Victoria Department of Transport, 2012). Additional benefits can be substantial, as reveals the 25% increase in benefits for the London CrossRail project[1] (DfT, 2005). Nevertheless, none of the above mentioned studies take into account the environmental impact generated by an increased accessibility, namely commuting. Correcting agglomeration economies brings new perspectives on transportation project appraisals and allows a better allocation of public funds.

3 Data and descriptive statistics

'A fine level of geographical details' is required to obtain accurate estimates (Ciccone, 2002). For this purpose, we choose to draw our analysis at the employment area level. So far, very few studies investigated the effects of agglomeration at the employment area level (see Combes et al., 2008, 2010). Most studies use larger spatial units, such as NUTS 3 areas[2] (Ciccone, 2002; Rice et al., 2006; and Combes et al., 2011). French employment areas were defined in 1983 and modified several times thereafter (1994, 1999 and 2010). They are smaller than NUTS 3 areas (French "Departments"), but larger than LAU 1 areas[3] (French "Cantons"). Furthermore and contrary to NUTS or LAU areas, their boarders are defined by commuting patterns and not administratively. It is admitted that at least 75% of the labor force live and work within the same employment area. Most employment areas correspond to a metropolitan area or to a city and its catchment area (see Figure 3 in Appendix). Thus, analyzing the effects of transportation infrastructure on employment areas seems all the more relevant, since they are built on commuting trips. Moreover, small spatial units such as employment areas constitute the appropriate spatial level for studying productivity issues since it has been demonstrated that agglomeration effects decrease rapidly with distance and mainly arise within 80 km.

In 2010, Metropolitan France is made up of 304 employment areas. We use cross-sectional data for the year 2009. Our data are aggregated at the employment area level. We combine data from General Census of Population with data on employment and wages for the year 2009. All data are derived from INSEE (French Institute of Statistics and

[1]The CrossRail project in London is an underground east-west rail link connecting existing rail networks on each side of the city (DfT, 2005).

[2]NUTS stands for Nomenclature of Territorial Units for Statistics.

[3]LAU stands for Local Administrative Unit.

Economic Studies). They are disaggregated at the industry level into five sectors (agriculture, manufacturing, construction, trade and services, public administration), and then pooled. The database is a two-dimension panel: employment areas X industries, and consists of 1,520 observations. We use workplace-based data on wages (File 'Rémunérations') to approximate labor productivity. To obtain employment densities, we use data on the number of jobs (File 'postes') divided by the surface areas. Surface areas are in square kilometers. The variable 'specialization' is constructed with the employment share of each sector in total area. The measure ranges from 0 when nobody works in a specific sector to 1 when total employment of the area is concentrated in this sector. We use as a measure of diversity the inverse of Herfindhal Index, applying data on sectoral employment. The measure equals 1 when jobs are concentrated in one sector, 5 when they are perfectly divided into the 5 sectors considered. The market potential of a zone is the sum of the opportunities derived from all the other zones while considering the distance between this zone and all the other ones. Opportunities in a zone are defined as its employment density divided by the distance to this zone. Since French employment areas are built on commuting patterns, it can be assumed that employment centers are usually located at the centroid of the area. Since it constitutes a more accurate measure of accessibility than Euclidean distance, we compute real road network distances with a Geographical Information System[4] to build the market potential variable.

Table 1: Summary statistics

Variables	Obs.	Mean	Std. Dev.	Min	Max
Productivity	1520	24869.65	4454.297	11988.95	49399.54
Density	1520	65.65865	315.1633	2.48	5124.87
Area	1520	1796.865	1390.345	119.4	8752
Specialization	1520	0.2	0.1505393	0.0002394	0.6401972
Diversity	1520	3.229865	0.3341255	2.086752	4.290933
Market Potential	1520	83.6658	57.50808	25.21517	480.528

Figure 1 and Figure 2 illustrate the underlying intuition behind agglomeration economies. Labor productivity is likely to be correlated with employment density.

4 The standard model

4.1 The general framework

We estimate the effects of employment density on labor productivity per worker. The basic framework has recently been enhanced by additional explanatory variables measuring urbanization economies, such as accessibility measured as a market potential, surface

[4]Distances are computed using calcdist-280.mbx tool on MapInfo. The software calculates distances between the centroids of each French employment areas.

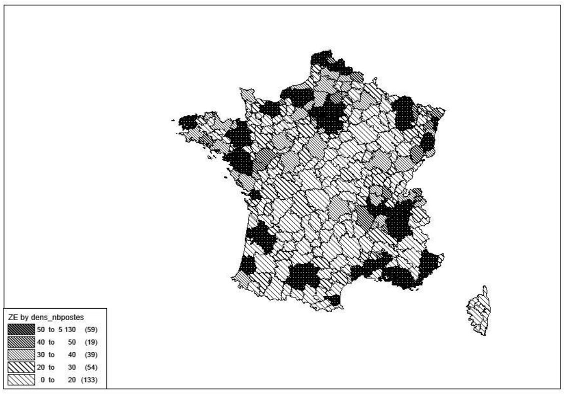

Figure 1: Employment density in French employment areas

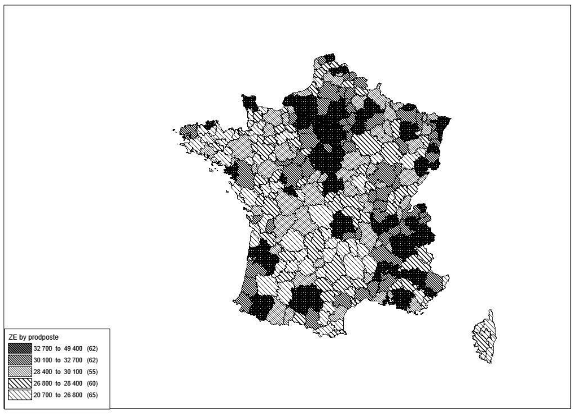

Figure 2: Worker productivity in French employment areas

area, and economic diversity. Sectoral specialization is often added to identify localization economies. Variables used in the general econometric specification are described below.

In the literature, we observe two main approaches measuring labor productivity. First, productivity can be estimated with the help of a production function using data on value added, since agglomeration economies lead to increased total factor productivity (Rosenthal and Strange, 2004). Second, wage equations are commonly in use to approximate productivity, assuming that at the competitive equilibrium workers receive wages equal to their marginal labor productivity. Rice et al. (2006) show the existence of a strong correlation (0.76) between these two kinds of productivity variables, namely gross value added per employee per hour worked and average hourly earnings. Moreover, the authors stress the fact that for small areas measuring productivity with gross value added may be biased by the spatial allocation of non-wage incomes. Following Combes et al. (2008, 2011), this article takes the average wage per worker as dependent variable. As prescribed by Moretti (2004), we use nominal wages.

Various measures of concentration are found. Some authors focus on employment, population or industry size (Sveikauskas, 1975; Segal, 1976; Henderson, 1986) or working age population size (Rice and al., 2006), while others apply measures of density. Ciccone and Hall (1996) define density as 'the intensity of labor, human, and physical capital relative to physical space'. They are the first to propose a framework investigating the effects of employment density on labor productivity. Density is a continuous variable that is far less sensitive to the geographic boundaries used than measures of size. Following the recent studies by Combes et al. (2008, 2011), we use the employment density as a measure of concentration.

When people and goods are mobile, employment areas are interconnected by migration and trade flows. These interactions have an influence on labor productivity (Head and Mayer, 2004, 2006). In the literature, two families of accessibility measures are in use: effective density and market potential (Matas et al., 2013). The effective density, as applied by Graham (2007) and Matas et al. (2013), is a comprehensive measure of both the accessibility to activity concentration within a specific area and from this area to the other areas. The market potential, derived from Harris (1954) and applied by Combes et al. (2008, 2011), measures only the accessibility to activity concentration of a particular area to the other areas[5]. For this reason, in any specification the market potential has to be used jointly with a measure of the size or density for each area. In this article, we use the market potential variable, since it best allows for discriminating between the effect of density and the effect of accessibility. It is worth noting that changes in transportation infrastructure or policy modify the market potential of a particular area since the relative proximities of activity is altered.

The surface of employment areas is added in order to distinguish density effects from pure scale effects. Indeed, surfaces vary significantly between areas and can impact density effects. Moreover, it is common to introduce a diversity index to capture the local distribution of jobs between the various economic sectors, as well as a measure of sectoral specialization to indicate the within-industry concentration.

The general specification is the following:

$$\ln prod_{zs} = \alpha + \beta \ln dens_z + \gamma \ln MP_z + \delta \ln area_z + \eta \ln \mathrm{div}_z + \theta \ln spe_{zs} + \varepsilon_{zs}$$

where $prod_{zs}$ is the average labor productivity per worker for sector s in zone z, $dens_z$ the employment density in zone z, MP_z the market potential of zone z, $area_z$ the surface of employment area z, div_z a measure of the economic diversity of zone z, spe_{zs} the average sectoral specialization of zone z, and ε_{zs} the error term. All variables are measured at the employment area level. In line with the recent literature, we use logs of the variables. The coefficient estimates are then interpreted as elasticities with respect to the different variables.

Table 2 shows the correlation between all variables. As expected, the variable 'productivity' is clearly and positively correlated with the variable 'density'. Table 2 also indicates that the specialization of the area is a factor contributing to higher productivity. In addition, results reveal that density and accessibility are strongly correlated. Specialization, density and the market potential seem to have a positive correlation with labor productivity. Employment area surface and diversity are negatively correlated with labor productivity.

Table 3 presents estimation results for robust OLS in the general framework. Variables are introduced successively according to the importance of their correlation with productivity. In line with the literature, we find an elasticity of productivity with respect to density of 0.05. All estimated variables are significant at the 1% level. Market potential is positive and highly significant too. Its magnitude is comparable to that of density. Both specialization of a zone and its surface impact positively labor productivity. Like Combes et al. (2008) on employment areas, the coefficient for economic diversity is negative.

[5] A limit of the market potential measure is that accessibility to foreign countries is not accounted for. This may bias coefficient estimates of border areas.

Table 2: Correlation matrix

Variables	ln *prod*	ln *dens*	ln *area*	ln *spe*	ln *div*	ln *MP*
ln *prod*	1.0000					
ln *dens*	0.3401	1.0000				
ln *area*	-0.0146	-0.3192	1.0000			
ln *spe*	0.3505	-0.0962	0.0268	1.0000		
ln *div*	-0.2181	-0.4059	-0.0078	0.1176	1.0000	
ln *MP*	0.2089	0.4244	-0.3144	-0.0452	-0.0435	1.0000

Table 3: Estimation results for robust Ordinary Least Squares (OLS)

Variables	OLS1	OLS2	OLS3	OLS4	OLS5
ln *spe*	0.0448***	0.0495***	0.0495***	0.0496***	0.0509***
ln *dens*		0.0638***	0.0580***	0.0629***	0.0517***
ln *MP*			0.0286**	0.0385***	0.0447***
ln *area*				0.0294***	0.0254***
ln *div*					-0.2166***
constant	10.2033***	10.0071***	9.9034***	9.6335***	9.9272***
N	1520	1520	1520	1520	1520
R^2	0.123	0.264	0.269	0.283	0.298

Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

4.2 Controlling for endogeneity issues

The OLS method assumes that the explanatory variables are uncorrelated with the error term. Otherwise, coefficient estimates are biased. Yet, two potential sources of endogeneity are identified in standard econometric specifications related to agglomeration economies: simultaneity bias and omitted variable bias. Simultaneity bias, also called reverse causality, arises if firms or workers migrate to locations with high productivity, leading therefore to higher densities. Graham et al. (2010) analyze the direction of causality between productivity and agglomeration and find substantial evidence of reverse causality, in particular for localization economies. This bias would lead to a 20% overestimation of agglomeration economies (Combes and Lafourcade, 2012; Combes et al., 2008, 2011). Omitted variable bias, or unobserved heterogeneity, is particular features impacting productivity but which are not explicitly accounted for in the specification. For instance, the industry mix of a zone or specific geographic characteristics (e.g. climate or relief) may impact productivity (Combes et al., 2010). Factor endowments such as public goods or natural resources play as well a role in determining productivity levels. The level of education of workers is also a leading determinant for wages (Ciccone and Hall, 1996; Combes et al., 2011). Agglomeration effects can be either over- or underestimated when variables are omitted.

Combes and Lafourcade (2012) provide a literature review of the solutions usually implemented to correct these biases. The most common approach to deal with the simultaneity bias is to use long lags on population size or population density as instrumental variables (Ciccone and Hall, 1996; Rice et al., 2006; Combes et al., 2008, 2010, 2011). The underlying assumption is that previous patterns of population concentration are correlated with current population or employment densities (the endogenous variable), but are independent from current labor productivity. Since both density and market potential are likely to be endogenous, we instrument both variables. We first instrument employment density using NUTS 3 population densities from 1866 and 1891. We then instrument market potential using NUTS 3 population density from 1866 over inter-zones distances as a measure. Then, unobservable heterogeneity can be controlled for by introducing fixed effects (Glaeser and Maré, 2001). In this study, we use industry fixed effects to control for sectoral heterogeneity.

Furthermore, firm selection issues may also lead to biased agglomeration effects. Firm selection refers to the fact that large and dense markets are more competitive and hence exclude less productive firms. Therefore, higher productivity in larger or denser areas is the result of a selection process, where only the more productive firms survived. However, Combes et al. (2012) reveal that firm selection is not an important bias for agglomeration economies estimates.

Table 4 shows results for various estimations of standard agglomeration economies. Introducing industry fixed-effects slightly modifies the coefficients. Moreover, industry fixed-effects raise the R^2 significantly. Instrumenting potentially endogenous variables leads to a slight increase in the density coefficient, from 0.050 to 0.055. Results are in line with the literature when education is not accounted for[6]. We also observe that the magnitude and significance of market potential decrease after addressing endogeneity issues.

The Stock and Yogo critical values for the Cragg-Donald F-Statistic are 13.43 for 10% maximum IV bias. The endogeneity C-stat confirms that instrumentation is needed for density and market potential. According to the Cragg-Donald F-stat and Kleibergen-Paap statistic, instruments are not weak. The Hansen J-stat shows that the set of instruments is exogenous.

Finally, given the spatial nature of the study, we check the spatial autocorrelation by computing the Moran's Index. For this purpose, we build a rook weights matrix, *i.e.*, a contiguity-based matrix in which contiguity is defined by shared boarders. The p-value for the Moran's I statistic (0.53) indicates that we cannot reject the null hypothesis of no spatial autocorrelation. Therefore, there is no need to use spatial econometric models.

[6] As highlighted in Combes et al. (2011), introducing the human capital decreases significantly the magnitude of density effects for recent periods. Ciccone and Hall (1996) and Combes and Lafourcade (2012) also warn against the existence of a sorting effect. Highly-skilled workers tend to concentrate in densely populated areas, and they get accordingly higher wages. Variables related to workers' education must be added to the specification in order to control for heterogeneity of skills among workers. However and as this paper aims at correcting 'standard' estimates of agglomeration economies with pollution features, we prefer to keep the specification as standard as possible.

Table 4: Standard agglomeration economies: results for various estimation methods

Variables	OLS5	OLS6	IV1	IV2
ln *dens*	0.0517***	0.0504***	0.0555***	0.0554***
ln *MP*	0.0447***	0.0435***	0.0249*	0.0249*
ln *area*	0.0254***	0.0257***	0.0182***	0.0182***
ln *div*	-0.2166***	-0.1895***	-0.2715***	-0.2711***
ln *spe*	0.0509***	0.0290**	0.0271***	0.0272***
constant	9.9272***	9.8011***	-	-
Industry fixed-effects	No	Yes	Yes	Yes
N	1520	1520	1520	1520
R^2	0.298	0.592	-	-
Cragg-Donald F-stat	-	-	383.224	383.224
Kleibergen-Paap Statistic	-	-	300.934	300.934
Hansen J-Stat	-	-	0.002	0.002
Chi-sq P-value	-	-	0.9631	0.9631
Endogeneity C-stat	-	-	32.327	32.327
Chi-sq P-value	-	-	0.000	0.000

Note: OLS5: No fixed-effects; OLS6: Industry fixed-effects; IV1: Generalized Method of Moments (GMM); IV2: Two Step Least Squares (2SLS); IV1 and IV2: we use log of NUTS 3 population density from 1866 and 1891 to instrument the variable 'ln *dens*'. Variable 'ln *MP*' is instrumented by the log of the market potential with population density from 1866. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

5 The extended model: including NO_X emissions

5.1 The effect of pollution on health and productivity

The link between pollution and health has first been assessed through epidemiologic studies on mortality rates. For instance, Lave and Seskin (1970) measure the long-term effects of sulfur oxides and particulates on mortality rates. Then, studies have been carried out on the effects of pollution on morbidity, focusing on variations in labor supply. Ostro (1983) demonstrates that a 10% increase in particulate levels generates a 4.4% decrease in work loss days. Carson et al. (2011) evidence a 8% decrease in household labor supply in Bangladesh due to arsenic exposure. Hanna and Oliva (2011) show that a 1% increase in sulfur dioxide results in a 0.61% decrease in the hours worked in Mexico City. These studies generally use hospital outcomes such as length of stay, emergency room visits, or work loss days to measure the impact of several pollutants on health. However, air pollution may affect not only the extensive margin, but also the intensive margin, that is labor productivity. Graff Zivin and Neidell (2012) first demonstrate the impact of ozone pollution on the productivity of agricultural workers in California. Ozone pollution diminishes lung functioning and negatively impacts productivity in physical work, even when the labor supply remains unchanged. Suglia et al. (2008) show that children living near higher levels of fine particulates perform worse on cognitive tests. Similarly, Lavy et al. (2012) find a negative relationship between both fine particulate matter and carbon monoxide and cognitive performance during school tests. They show that altered cognitive performance results in mis-ranking of students. This may result in inefficient allocation of workers across occupations, and negatively affect labor productivity, especially for intellectual work. In this sense, environmental protection is considered as an investment in human capital sustaining labor productivity and therefore economic growth (Graff Zivin and Neidell, 2012).

In this work, we focus on nitrogen oxide (NO_X). Nitrogen oxide (NO_X) is made of nitric oxide (NO) and nitrogen dioxide (NO2). NO2 is highly toxic and penetrate into the lungs, therefore causing respiratory diseases. NO irritates bronchi and diminishes the oxygen power of blood. Sensitive groups are also the most affected by NO_X exposure. NO_X emissions result mainly from transport (61%, among which 93% from road transport) due to the exhaust of diesel vehicles.

Although NO_X emissions are on a deceasing trend (-45% in France over the period 1990-2011) (CITEPA, 2013), their actual level remains harmful for health. Furthermore, this pollutant affects the environment. NO_X are among air pollutants causing acid rains. They also contribute to ozone pollution and to climate change. Although environmental effects are not accounted for in our specification, they are relevant and could be integrated in future analysis.

5.2 The extended specification

5.2.1 First estimations

In this article, we use data on NO_X emissions for the year 2009 at the NUTS 2 level (French "regions"). Emissions are obtained from each regional AASQA (Association Agrééе de Surveillance de la Qualité de l'Air, which is the French regional association for air quality monitoring). Since the specification is defined at an aggregated level, we apply emissions that are a computed and aggregated measure of concentrations recorded at each particular monitoring station. We are aware of the fact that air quality affecting human health is best approximated by concentration levels of pollutants. The relation between concentrations and emissions is complex. For a given level of emissions, concentrations vary depending on meteorological and physical features such as wind, temperature, humidity, precipitation, topography and the height of buildings. In order to partly avoid such bias, we use spatial units much larger than employment areas. Indeed, larger units would better account for wind effects. We obtained pollution data for 21 of the 22 French regions. The following results are therefore drawn on a slightly smaller number of observations than the standard model presented above.

The extended specification is based on the general framework presented in section 4.1. and includes the pollution variable for a zone z, noted '$poll_z$'.

$$\ln prod_{zs} = \alpha + \beta \ln dens_z + \gamma \ln MP_z + \delta \ln area_z + \eta \ln \mathrm{div}_z + \theta \ln spe_{zs} + \lambda \ln poll_z + \varepsilon_{zs}$$

We test the impact of NO_X emissions per worker on labor productivity. We integrate the air pollution variable in the general model. Since Lavy et al. (2012) find that pollution has a non-linear impact on productivity, we use the logarithmic form.

Table 5 represents the correlation matrix between all the variables of the general framework and the NO_X emissions variable. Since correlations between standard agglomeration economies variables are quite similar, complete correlation matrix is not presented in this section. As expected, the correlation matrix shows that NO_X is negatively correlated with labor productivity.

Table 5: Correlation matrix for NO_X emissions

Variables	ln NO_X
ln *prod*	-0.2316
ln *dens*	-0.3255
ln *area*	0.2491
ln *spe*	0.0581
ln *div*	0.2686
ln *MP*	-0.3568
ln NO_X	1.0000

Table 6 presents the effect of NO_X emissions on labor productivity. NO_X emissions by worker have a negative and significant effect at the 1% level on labor productivity. Results show that a 1% increase in NO_X emissions lowers labor productivity by almost 0.07%.

5.2.2 Controlling for endogeneity issues

We are aware of the potential endogeneity bias affecting the pollution variable (reverse causality). On one hand, the literature introduced above highlights the causal link between pollution and productivity: pollution impacts negatively labor productivity. On the other hand, productive regions are likely to pollute more. Therefore, the causal link between pollution and productivity may be reversed.

Previous results constitute first estimations of the effect of air pollution on productivity. They could be enhanced with instrumental variables, such as car ownership rates. We expect NO_X emissions to be positively correlated with car ownership rates. Generally, high levels of car ownership rates mean higher car availability, and therefore more trips carried out by car, resulting in higher levels of air pollution. In addition, car ownership rates may also be correlated with productivity, since higher wages facilitate access to cars. Nevertheless, car ownership patterns change rapidly overtime, and we expect lagged car ownership rates not to be correlated with present wages. We use car ownership rates from 1999 as instrument for pollution emissions.

Table 7 presents results for the extended specification when the endogeneity of the pollution variable is controlled. The results slightly differ from the first estimations presented above. The density coefficient is reduced from 0.0265 to 0.0253, which indicates that the positive effect of density on productivity is lowered when the endogeneity of the

Table 6: The effect of air pollution on productivity

	OLS1	OLS2	IV1	IV2
ln *dens*	0.0526***	0.0514***	0.0265***	0.0265***
ln *MP*	0.0374***	0.0365***	0.0452***	0.0452***
ln *area*	0.0328***	0.0329***	0.0242***	0.0241***
ln *div*	-0.1456**	-0.1229**	-0.2137***	-0.2131***
ln *spe*	0.0515***	0.0323**	0.0279**	0.0279**
ln NO_X	-0.0602***	-0.0595***	-0.0655***	-0.0654***
constant	9.6422***	9.5364***	-	-
Industry fixed-effects	No	Yes	Yes	Yes
N	1485	1485	1485	1485
R^2	0.318	0.617	-	-
Cragg-Donald F-stat	-	-	359.202	359.202
Kleibergen-Paap Statistic	-	-	300.707	300.707
Hansen J-stat	-	-	0.006	0.006
Chi-sq P-value	-	-	0.9378	0.9378
Endogeneity C-stat	-	-	32.266	32.266
Chi-sq P-value	-	-	0.0000	0.0000

Note: OLS1: No fixed-effects; OLS2: Industry fixed-effects; IV1: Generalized Method of Moments (GMM); IV2: Two Step Least Squares (2SLS); IV1 and IV2: we use log of NUTS 3 population density from 1866 and 1891 to instrument the variable 'ln *dens*'. Variable 'ln *MP*' is instrumented by the log of the market potential with population density from 1866. The Stock and Yogo critical values for the Cragg-Donald F-Statistic are 13.43 for 10% maximum IV bias. As demonstrated in section 4.2., instrumentation is needed because of endogeneity problems. Besides, the set of instruments is not weak and is exogenous. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

pollution variable is controlled. In addition, the NO_X emissions coefficient decreases from -0.0655 to -0.1031, which indicates a stronger negative effect of pollution on productivity. The impact of air pollution on labor productivity remains negative and highly significant, with a 1% increase in air pollution leading to a 0.1% decrease in productivity. According to the standard tests on instrumented variables, the set of instruments used is valid.

In addition, we test the interaction between NO_X emissions and density. The interaction term (-0.0186) is negative and significant at the 5% level, which is in line with the results of the literature on local air pollutants. Consequently, NO_X emissions impact negatively the effect of density on productivity. The denser an area, the more polluted it is, and the more acute health problems will be. Indeed, health problems directly impact workers' productivity, as demonstrated in the literature.

Table 7: The effect of air pollution on productivity after controlling for endogeneity biases

	IV1	IV3
ln *dens*	0.0265***	0.0253***
ln *MP*	0.0452***	0.0373***
ln *area*	0.0242***	0.0266***
ln *div*	-0.2137***	-0.1881***
ln *spe*	0.0279**	0.0285**
ln NO_X	-0.0655***	-0.1031***
Industry fixed-effects	Yes	Yes
N	1485	1485
Cragg-Donald F-stat	359.202	81.291
Kleibergen-Paap Statistic	300.707	51.135
Hansen J-stat	0.006	0.116
Chi-sq P-value	0.9378	0.7334
Endogeneity C-stat	32.266	32.878
Chi-sq P-value	0.0000	0.0000

Note: IV1: Generalized Method of Moments (GMM); IV3: Generalized Method of Moments (GMM); IV1 and IV3: we use log of NUTS 3 population density from 1866 and 1891 to instrument the variable 'ln *dens*'. Variable 'ln *MP*' is instrumented by the log of the market potential with population density from 1866; IV3: we use log of car ownership rates from 1999 at the employment area level to instrument the pollution variable, NO_X. The Endogeneity C-Stat indicates that instrumentation is needed. Besides, the set of instruments is not weak and is exogenous. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

6 How air pollution reduces agglomeration gains

6.1 Comparing both econometric models

Agglomeration gains are revealed by the elasticity of productivity with respect to density. Estimating the magnitude of the correction of the agglomeration economies requires the comparison between the density coefficients of both models, namely the standard model and the extended model. For this purpose, identical samples are needed. Table 8 presents the results of the standard model on the same sample as the extended model presented in Table 7.

When pollution is accounted for, the density coefficient decreases from 0.0287 to 0.0253, which clearly highlights a reduction in the positive effect of density on productivity. A 1% increase in density now leads to a 0.025% increase in labor productivity, instead of the standard 0.029% increase in productivity. Agglomeration economies are therefore reduced when pollution is introduced in the model.

Table 8: Comparison between the standard and the extended specification

	IV3	IV4
ln *dens*	0.0253***	0.0287***
ln *MP*	0.0373***	0.0589***
ln *area*	0.0266***	0.0200***
ln *div*	-0.1881***	-0.2572***
ln *spe*	0.0285**	0.0268*
ln NO_X	-0.1031***	-
Industry fixed-effects	Yes	Yes
N	1485	1485
Cragg-Donald F-stat	81.291	361.373
Kleibergen-Paap Statistic	51.135	302.372
Hansen J-stat	0.116	0.141
Chi-sq P-value	0.7334	0.7071
Endogeneity C-stat	32.878	29.103
Chi-sq P-value	0.0000	0.0000

Note: IV3: Generalized Method of Moments (GMM) for the extended specification; IV4: Generalized Method of Moments (GMM) for the standard specification; IV3 and IV4: we use log of NUTS 3 population density from 1866 and 1891 to instrument the variable 'ln *dens*'. Variable 'ln *MP*' is instrumented by the log of the market potential with population density from 1866; IV3: we use log of car ownership rates from 1999 at the employment area level to instrument the pollution variable, NO_X. The Endogeneity C-Stat indicates that instrumentation is needed. Besides, the set of instruments is not weak and is exogenous. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

6.2 Estimating the reduction in agglomeration gains: the illustrative case

For the illustrative case, let us assume a representative employment area of 700 square kilometers with a GDP of 5 billion euros and 70,000 workers. We assume the introduction a new structural transportation infrastructure such as a Bus with High Level of Service (BHLS). The infrastructure is expected to create 1,000 new jobs in the employment area. These hypothesis are totally fictional. The aim of the illustrative case is to provide rough estimates of the reduction in agglomeration economies and to monetarize this loss of wealth.

Due to the implementation of the new transportation infrastructure, the density of the employement area increases by 1.4%. The productivity differential with respect to density is 0.0399% when air pollution is ignored, against 0.0352% when pollution is accounted for. This results in a productivity gain of 28.5 and 25.14 euros per worker, respectively. The agglomeration gains from the 71,000 final workers amount to 2,023,500 euros when pollution is ignored, against 1,784,940 euros when pollution is considered. Therefore, accounting for air pollution reduces the expected agglomeration gains by 13.4%. A 1%

increase in NO_X emissions reduces the productivity by 0.1%, which corresponds to an economic loss of 238,560 euros for the given level of GDP. The GDP growth expected with the implementation of the new transportation infrastructure is 0.04% when pollution is ignored, against 0.036% when pollution is taken into account. To conclude, considering the aforementioned assumptions, such an infrastructure is expected to generate negligible wealth creation, and a more negligible one when pollution is accounted for. As a result, the illustrative case allows to put into perspective the expected wealth creation resulting from the implementation of a new transportation infrastructure or policy.

7 Concluding remarks

This article enlarges the general framework that studies determinants of agglomeration economies and explores the impact of air pollution on worker productivity. It confirms that pollution has a negative and significant impact on productivity. Results show that taking into account air pollution in agglomeration economies estimations reduces their magnitude by more than 13%. Empirically, the main contribution of this paper is to include a pollution variable in the standard specification of agglomeration economies. The result indicates that air pollution is an omitted variable in standard econometric models estimating agglomeration economies. Even if agglomeration economies are substantial when implementing a new transport infrastructure or policy, a part of them should be corrected by the negative environmental impact from the trips induced by improved accessibility. This paper explicits the general intuition that pollution is harmful to health and that health problems affect negatively labor productivity. It is usually admitted that new transportation infrastructures or policies enhance accessibility and therefore productivity. However, improved accessibility induces new trips which generate increased air pollution. In this paper, we highlight that taking into account air pollution in agglomeration estimations reduces expected gains. This result provides guidance for policy-makers. For this reason, low-carbon transportation infrastructures or policies should be favored to ensure the lowest reduction in the expected agglomeration gains due to air pollution (e.g. car-sharing policies, bike-sharing systems). In addition, policies supporting mobility can be set, such as commuting costs subsidized by firms or mobility learning for young and disadvantaged population.

Results are obtained for a specific air pollutant, NO_X. Only direct effects are accounted for. It is usually admitted that pollution has cumulative effects on productivity and health. Further work would consist in introducing cumulative effects of air pollution to strengthen our results. In addition, other pollutants can be added to better reproduce air quality and to generalize our findings. Further work could use individual data to control for heterogeneity of workers, in particular with the inclusion of human capital variables such as education. Moreover, we could investigate the link between the contribution of human capital to agglomeration economies and its variations following the inclusion of pollution.

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Appendices

Appendix A: French employment areas

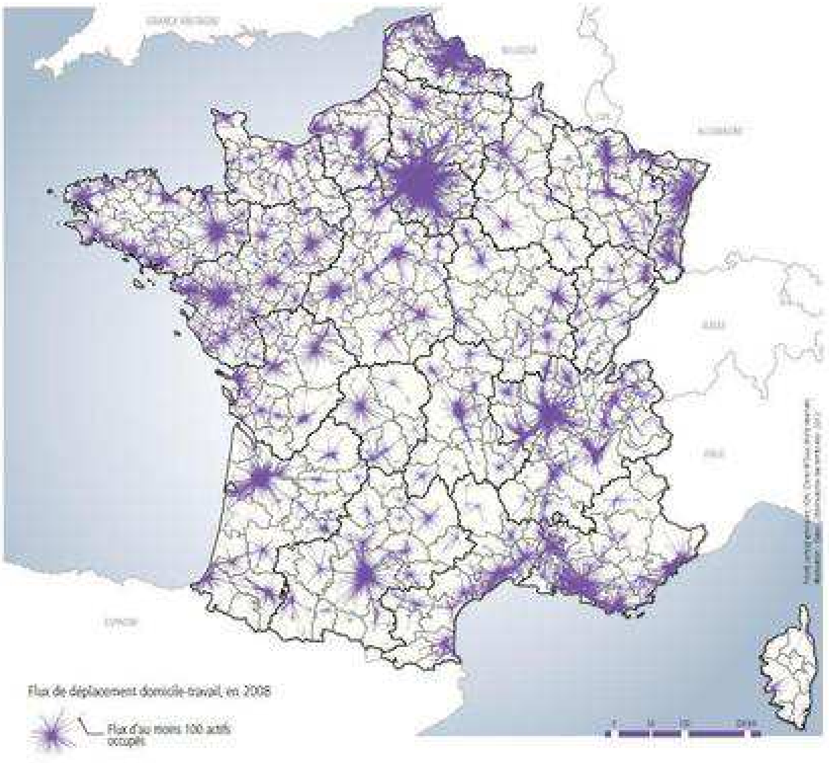

Figure 3: Commuting patterns define French employment areas. *Source*: INSEE, 2010

Appendix B: Interaction coefficient

Only the interaction term is of interest, while the other coefficients are not directly interpretable.

Table 9: Interaction coefficient

	IV5
ln *inter*	-0.0186*
ln NO_X	0.0105
ln *dens*	-0.0010
ln *MP*	0.0290***
ln *area*	0.0330***
ln *div*	-0.0776
ln *spe*	0.0375***
Industry fixed-effects	Yes
N	1485

Note: IV5: Generalized Method of Moments (GMM); we use log of NUTS 3 population density from 1866 and 1891 to instrument the variable 'ln *dens*'. Variable 'ln *MP*' is instrumented by the log of the market potential with population density from 1866; we use log of car ownership rates from 1999 at the employment area level to instrument the pollution variable, NO_X. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

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